AD-A045 448 MATERIALS RESEARCH LABS MARIBYRNONG (AUSTRALIA) F/G 20/5
HIGH-PRESSURE DISCHARGE FOR CO2 LASERS,(U)
MAY 77 R MCLEARY, P J BECKWITH
UNCLASSIFIED MRL-R-687 NL

| OF |
AD
A045448

END
DATE
FILMED
11 - 77
DDC

MRL-R-687 (12) AR-000-656

AD A045448

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

MATERIALS RESEARCH LABORATORIES

MELBOURNE, VICTORIA

REPORT

MRL-R-687

HIGH-PRESSURE DISCHARGE FOR CO_2 LASERS

R. McLeary and P.J. Beckwith

Approved for Public Release

MAY, 1977

DEPARTMENT OF DEFENCE

MATERIALS RESEARCH LABORATORIES

REPORT

14 MRL-R-687

6 HIGH-PRESSURE DISCHARGE FOR CO_2 LASERS

10 R. McLeary ~~and~~ P.J. Beckwith

11 May 77

12 17p.

ABSTRACT

This report describes the characteristics of continuous electric discharges stabilised by the plasma-injection technique. The gases investigated are N_2 and mixtures of N_2 and CO_2 that are suitable for use in CO_2 lasers. Discharge characteristics are presented for wide ranges of pressure, discharge length and gas mixture. Stable discharges in N_2 have been achieved at power densities up to 200 MW/m^3 (200 kW/litre) at atmospheric pressure.

cu.m.

Approved for Public Release

POSTAL ADDRESS: Chief Superintendent, Materials Research Laboratories
P.O. Box 50, Ascot Vale, Victoria 3032, Australia

DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

1. DOCUMENT NUMBERS: a. AR Number: AR-000-656 b. Series & Number: REPORT MRL-R-687 c. Report Number: MRL-R-687	2. SECURITY CLASSIFICATION: a. Complete document: UNCLASSIFIED b. Title in isolation: UNCLASSIFIED c. Abstract in isolation: UNCLASSIFIED
3. TITLE: HIGH-PRESSURE DISCHARGE FOR CO_2 LASERS	
4. PERSONAL AUTHOR(S): McLEARY, R. and BECKWITH, P.J.	5. DOCUMENT DATE: MAY, 1977 6. TYPE OF REPORT & PERIOD COVERED:
7. CORPORATE AUTHOR(S): Materials Research Laboratories	8. REFERENCE NUMBERS: a. Task: DST 63/003 b. Sponsoring Agency: DST 9. COST CODE: 414520
10. IMPRINT (Publishing establishment) Materials Research Laboratories, P.O. Box 50, Ascot Vale, Vic.3032 MAY, 1977	11. COMPUTER PROGRAMME(S): (Title(s) and language(s)):

12. RELEASE LIMITATIONS (of the document):

Approved for Public Release

12-0. OVERSEAS: N.O. [ ] P.R. [1] A [ ] B [ ] C [ ] D [ ] E [ ]

13. ANNOUNCEMENT LIMITATIONS (of the information on this page):

No Limitation

14. DESCRIPTORS:

Carbon Dioxide Lasers	Gas Discharges
Lasers	Pressure
	Ionization

15. COSATI CODES: 2005

16. ABSTRACT (if this is security classified, the announcement of this report will be similarly classified):

This report describes the characteristics of continuous electric discharges stabilised by the plasma-injection technique. The gases investigated are N_2 and mixtures of N_2 and CO_2 that are suitable for use in CO_2 lasers. Discharge characteristics are presented for wide ranges of pressure, discharge length and gas mixture. Stable discharges in N_2 have been achieved at power densities up to 200 MW/m^3 (200 kW/litre) at atmospheric pressure.

CONTENTS

HIGH-PRESSURE DISCHARGE FOR CO_2 LASERS

INTRODUCTION

The development of the plasma-injection technique (1) for stabilising continuous electric discharges in CO_2 lasers has resulted in the construction of a multi-kilowatt laser (2) which operates at the relatively high pressure of 30 kPa. This laser is compact and reliable but is based on a discharge configuration which is difficult to scale, and output powers above about 10 kW are not easily achieved.

This report describes the electrical characteristics of discharges that can be scaled indefinitely in cross-sectional area and which may be extended to at least 120 mm in length. The discharges are stabilised by the injection of plasma from an array of subsidiary arc discharges (pin discharges) which originate on pin electrodes located near the apertures of a perforated (pin-hole) plate (Fig. 1). The gas in which the discharge is to be excited is injected at sonic velocity through these pin-holes, and the ionised or otherwise excited species which form in the pin discharges disperse over the main discharge volume. The injection of these excited species provides a background level of ionisation in the main discharge volume and inhibits the formation of discharge instabilities.

It has been found that the conductivity of such discharges is nearly independent of area. The results presented in the following section may therefore be extended to apply to discharges of larger area by appropriate scaling.

APPARATUS

The apparatus used in this investigation is shown in Fig. 2. The discharges were excited in a rectangular Perspex box with an internal cross-section of 20 mm x 50 mm, in which the discharge length could be varied up to a maximum of 120 mm by means of a movable mesh electrode. The box contained thirteen regularly spaced pins corresponding to a pin density of $1.3 \times 10^4\ m^{-2}$. A number of aluminium pin-hole plates were available with pin-hole diameters in the range 1.5 to 3.0 mm. The total pin current could be varied from 0.8 to 3.4 A, and the pressure in the main discharge region from 20 to 120 kPa by means of an adjustable restriction between the discharge region and the dump tank.

The apparatus was operated quasi-continuously, the gas being supplied from a "blow-down" reservoir and the electrical input from capacitor banks. Operating times were of the order of 100 ms, which was considerably longer than the maximum gas transit time of 11 ms (corresponding to a discharge length of 120 mm, a pressure of 120 kPa and a flow rate of 15 gs^{-1}). The main discharge voltage and current, the total pin current and the pressures upstream of the pin-hole plate and in the main discharge region were monitored during each run. These waveforms were essentially constant over the 20-ms monitoring time.

RESULTS

The discharge characteristics presented here were obtained with a pressure of 240 kPa upstream of the pin-hole plate. The flow rate was varied by the use of pin-hole plates having different pin-hole diameters.

A typical voltage-current characteristic for N_2 is shown in Fig. 3: the discharge length was 60 mm and the discharge pressure was 96 kPa, the total pin current was 2.5 A, and the N_2 flow rate was 34 gs^{-1}. This flow rate was obtained by the use of 2.3-mm diameter pin-holes. The characteristic is essentially a straight line through the origin up to an input power of approximately 14 kW, above which value the discharge becomes unstable. The positive slope of the line gives the discharge resistance which in this case is 20 kΩ. The discharge resistances obtained in this way are plotted in Fig. 4 as a function of pressure for various values of the total pin current, a N_2 flow rate of 34 gs^{-1} and a discharge length of 60 mm. Fig. 5 shows the resistance as a function of discharge length for a total pin current of 1.3 A and a N_2 flow rate of 34 gs^{-1} at a pressure of 100 kPa. The maximum discharge power as a function of length is shown in Fig. 6 for a N_2 pressure of 100 kPa, and for the pin currents and gas flow rates indicated. Fig. 7 shows the maximum power as a function of discharge pressure for a number of mixtures of N_2 and CO_2 and a total pin current of 1.3 A, a discharge length of 60 mm and a flow rate of 34 gs^{-1}.

It is to be noted from Figs. 6 and 7 that in the case of N_2 there is a difference of about 20% in the power density for similar discharge conditions (I_p = 1.3 A - 1.4 A, $\dot{m}$ = 34 gs^{-1}, L = 60 mm and P = 100 kPa). This may be due to the use of different gas cylinders in these two cases. It has been found that, in general, discharge characteristics are sensitive to impurities (especially O_2) in the gas mixtures.

The voltage on each pin electrode is in the range 1.0 to 1.5 kV, depending on the pin current. The total power dissipated in the pin discharges is therefore at most about 20% of the main discharge power.

DISCUSSION

The main emphasis in this investigation was on discharge performance over a range of operating conditions relevant to CO_2 lasers. Some general conclusions may be drawn from the data presented.

Discharge power densities of approximately 200 MW/m^3 may be achieved in N_2 at atmospheric pressure. The addition of 2% CO_2 decreases the maximum power density by a factor of two at this pressure. One reason for the decrease of power density with increasing CO_2 content is likely to be the rise in temperature of the gas caused by the depopulation of the vibrational energy states of N_2 by collisions with CO_2. At least 80% of the discharge energy goes into producing vibrationally excited N_2 molecules at the values of E/N (ratio of electric field to gas number density) obtained in these experiments (3). The addition of CO_2 provides a relatively fast means ($\sim$ 1 ms for 1% CO_2 at 100 kPa) of channelling this vibrational energy into translational energy in the gas.

It can be seen in Figs. 4 and 5 (which show discharge resistance as a function of pressure and discharge length) that the slopes of the curves are increasing at pressures approaching 120 kPa (Fig. 4), and at discharge lengths above about 100 mm (Fig. 5). This may be due to life-time processes associated with the excited species mentioned previously. The decrease in resistance at low pressures seems to be a result of a "jetting" action of the pin discharges. At low pressures the plasma jet from each pin-hole extends a significant distance across the main discharge region thereby decreasing the effective discharge length.

The precise mechanism underlying the operation of the plasma-injection technique has not so far been resolved. The role of the direct transportation of ions and electrons is likely to be small owing to the fast ion-electron recombination rates (4). A secondary ion-electron production process involving long-lived metastable species created in the pin discharges (5,6,7) appears to be the explanation for the observed conductivity of the gas.

APPLICATION TO HIGH-POWER LASERS

It is seen in Fig. 7 that the highest input powers are obtained with low CO_2 concentrations, at pressures of about 100 kPa. These conditions, however, give rise to problems of low gain and high saturation flux which make it difficult to extract optical power efficiently (8). The optimum operating conditions are consequently a compromise between the requirements of the discharge and the resonator. A laser with discharge dimensions of 20 mm x 60 mm x 1000 mm has been constructed and has been found to have an optimum operating pressure of about 30 kPa; quasi-continuous (10 ms duration) output powers of 8 kW have been achieved at this pressure with an efficiency (defined as the ratio of output power to the sum of the pin and main discharge powers) of 7%.

In applications where there is no requirement for the use of pre-mixed gas, the compactness and gain of a laser using this type of discharge can be significantly improved by the adoption of a mixing-laser configuration. The discharge can then be operated in pure N_2 at 100 kPa, allowing input power densities above 200 MW/m^3 to be attained, and the CO_2 and He can be mixed with the excited N_2 in a lower pressure region in which the optical power is extracted. When the laser mentioned earlier was operated in this way with a resonator pressure of 20 kPa, output powers of 30 kW were obtained at an efficiency of 12%.

It has been found that good overall performance is provided by a pin density of 10^4 m^{-2}, pin-hole diameters of 2 mm, individual pin currents of 100 mA, and a flow rate per pin-hole of 2 gs^{-1}. These parameters may however be varied widely to satisfy individual requirements.

CONCLUSION

The characteristics of continuous high-pressure discharges in N_2 and in N_2/CO_2 mixtures have been described, and the use of these discharges in CO_2 lasers has been discussed. Power densities of about 200 MW/m^3 have been obtained in a N_2 discharge at a pressure of 100 kPa, although the maximum power density decreases as CO_2 is added, and is reduced by a factor of about 2 by a CO_2 concentration of 2% at this pressure. Lasers based on these discharges have the advantages of being simple, rugged and reliable, and may be readily scaled to higher powers.

REFERENCES

1. McLeary, R., Beckwith, P.J. and Gibbs, W.E.K. (1974). "Uniform Continuous Discharges and CO_2 Laser Action at Atmospheric Pressure by Plasma Injection". IEEE J. Quantum Electron, QE-10, (9), 649-651.

2. Whitcher, R.E. and McLeary, R. (1976). "The Design of a High-Pressure Multi-Kilowatt CO_2 Laser". MRL Report 646.

3. Englehardt, A.G., Phelps, A.V. and Risk, C.G. (1964). "Determination of Momentum Transfer and Inelastic Collision Cross Sections for Electrons in Nitrogen Using Transport Coefficients". Phys. Rev., 135, (6A), 1566-1574.

4. Dutton, J. (1975). "A Survey of Electron Swarm Data". Journal of Physical and Chemical Reference Data, 4, (3), 577-856.

5. Lozansky, E.D. (1969). "The Mechanism of Secondary Processes in the Streamer Breakdown of Gases". Brit. J. Appl. Phys. : J. Phys. D., Ser. 2, 2, 137-139.

6. Crane, R.A., Ghosh, A.K. and Tam, S.Y.K. (1976). "Arc-Assisted Electric-Discharge Technique for High-Pressure CW CO_2 Lasers". J. Appl. Phys., 47, (7), 3357-3359.

7. Scarcy, J.Q. (1974). "A Supersonic Molecular Beam Metastable Atom Source Initiated by Direct Discharge". Rev. Sci. Instrum., 45, (4), 589-590.

8. McLeary, R. and Gibbs, W.E.K. (1973). "CW CO_2 Laser at Atmospheric Pressure". IEEE J. Quantum Electron., QE-9, (8), 828-833.

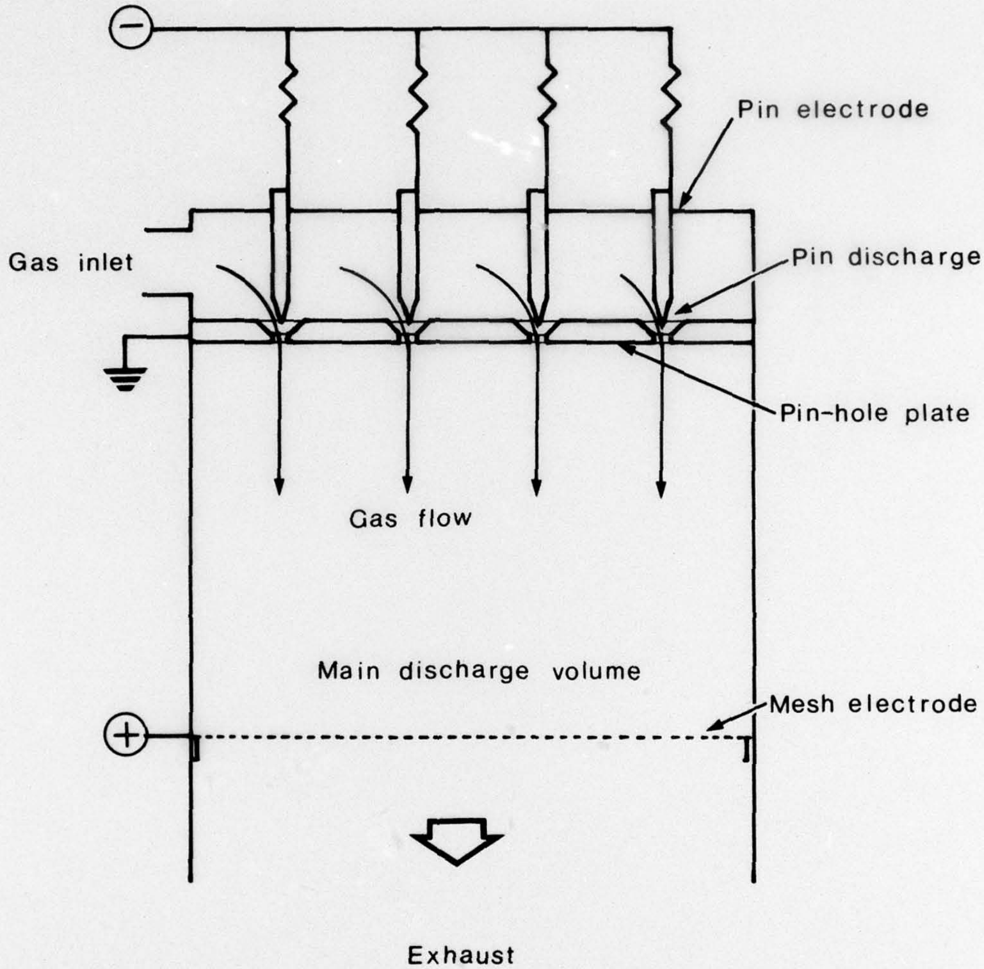

FIG. 1 - Basic arrangement for production of a plasma-injection-stabilised discharge.

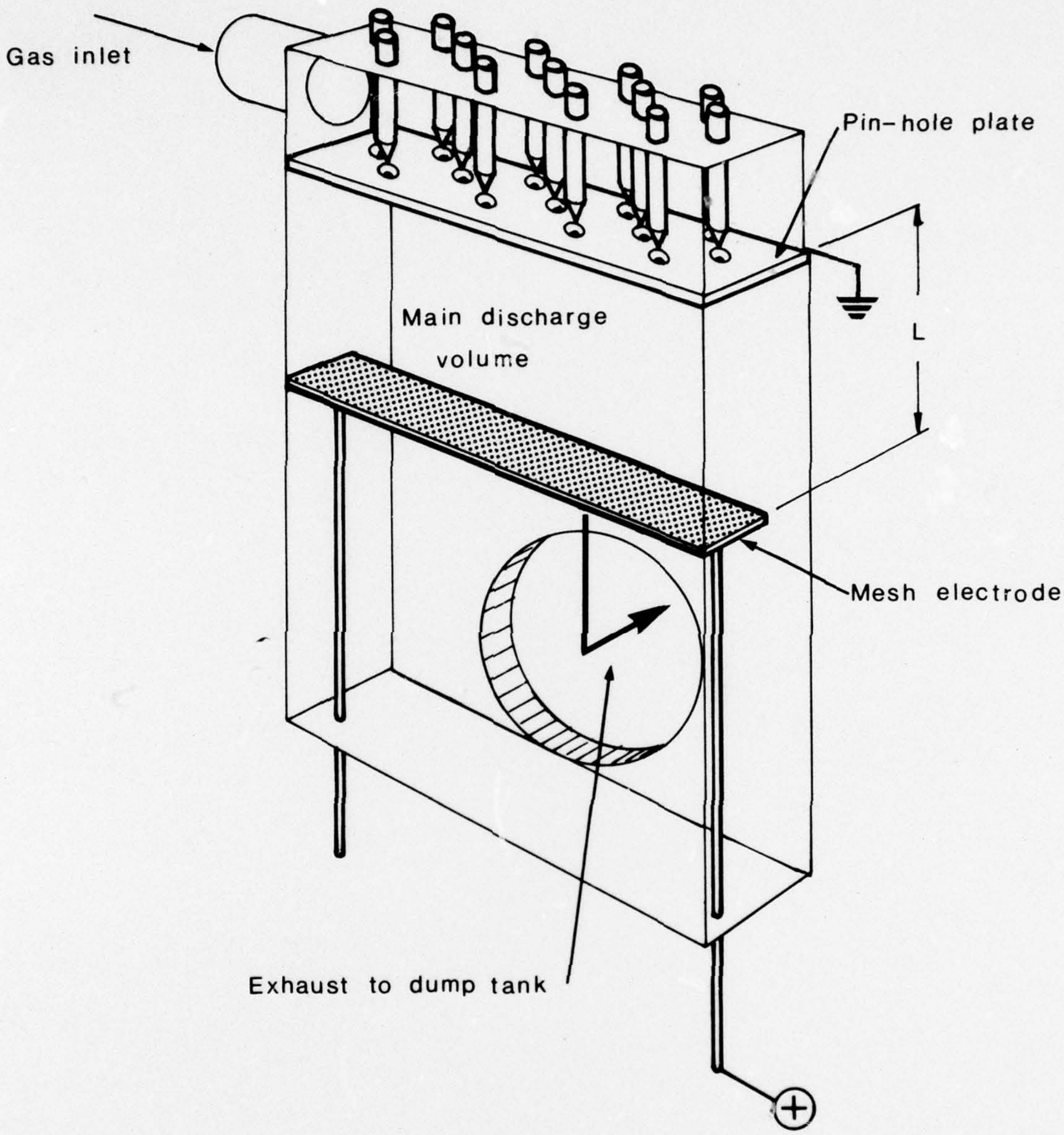

FIG. 2 - Diagram of experimental apparatus.

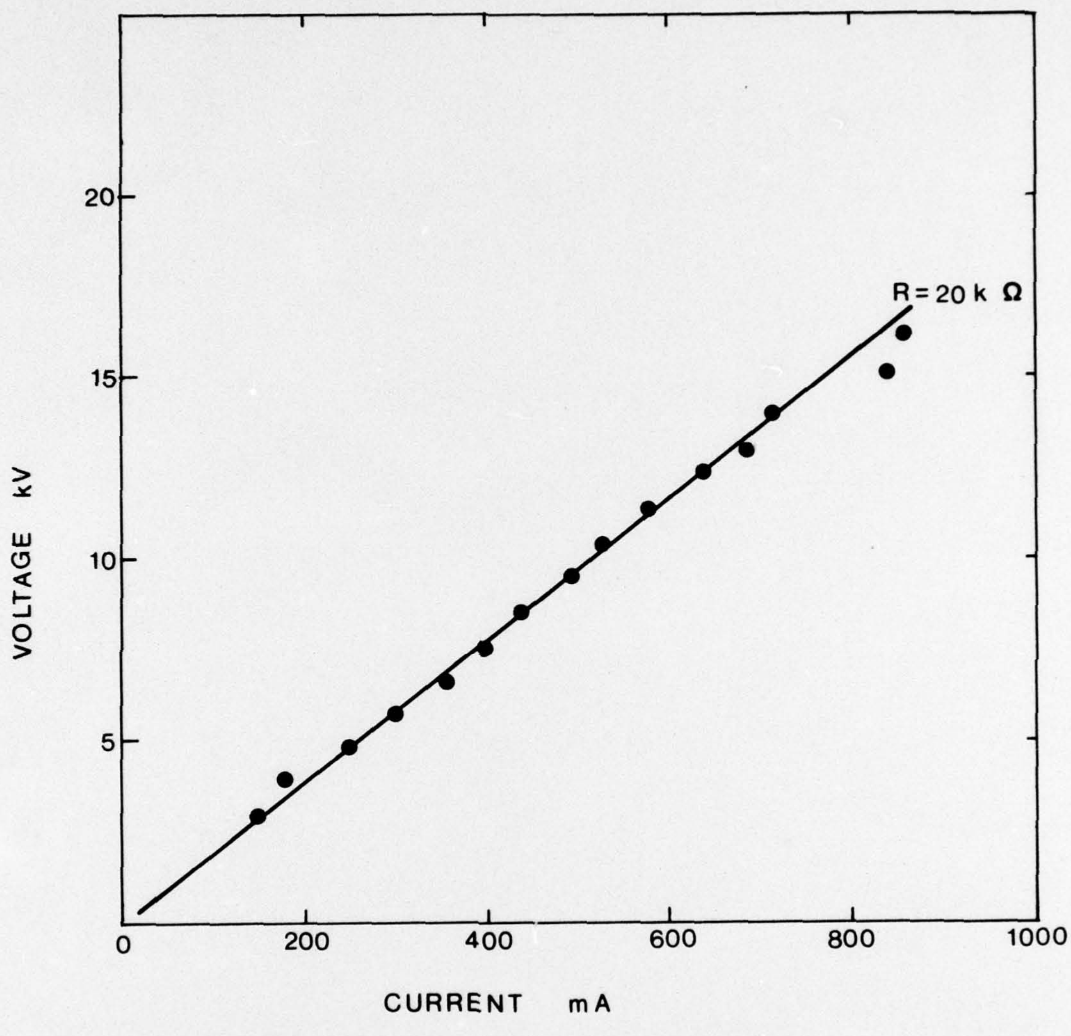

FIG. 3 - Current-voltage characteristics of the discharge in N_2 for a discharge length (L) = 60 mm, a total pin current (Ip) = 2.5 A, a flow rate ($\dot{m}$) = 34 gs^{-1}, and a pressure (P) = 96 kPa.

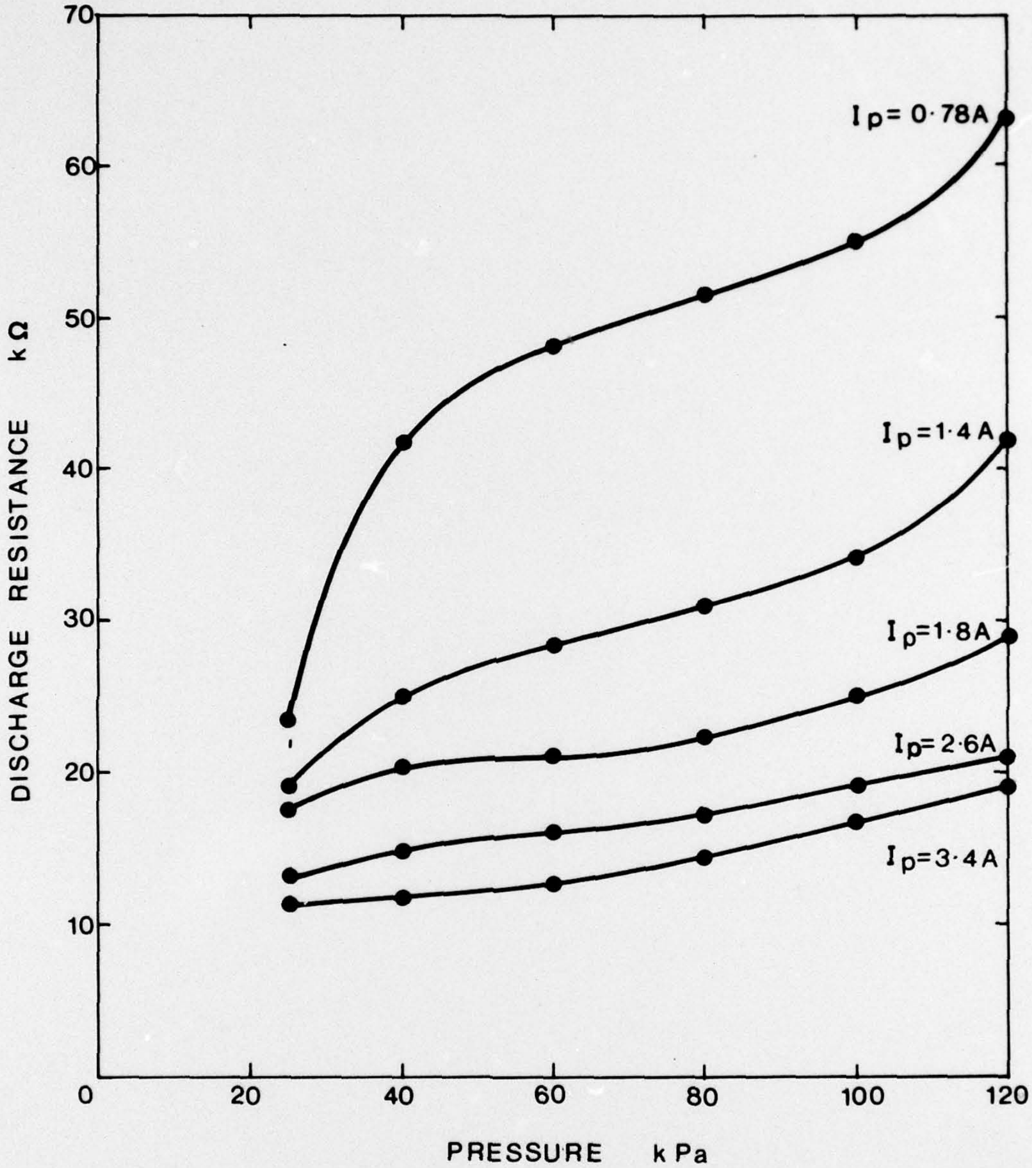

FIG. 4 - Discharge slope-resistance, in N_2, as a function of pressure, for L = 60 mm and $\dot{m}$ = 34 gs^{-1}.

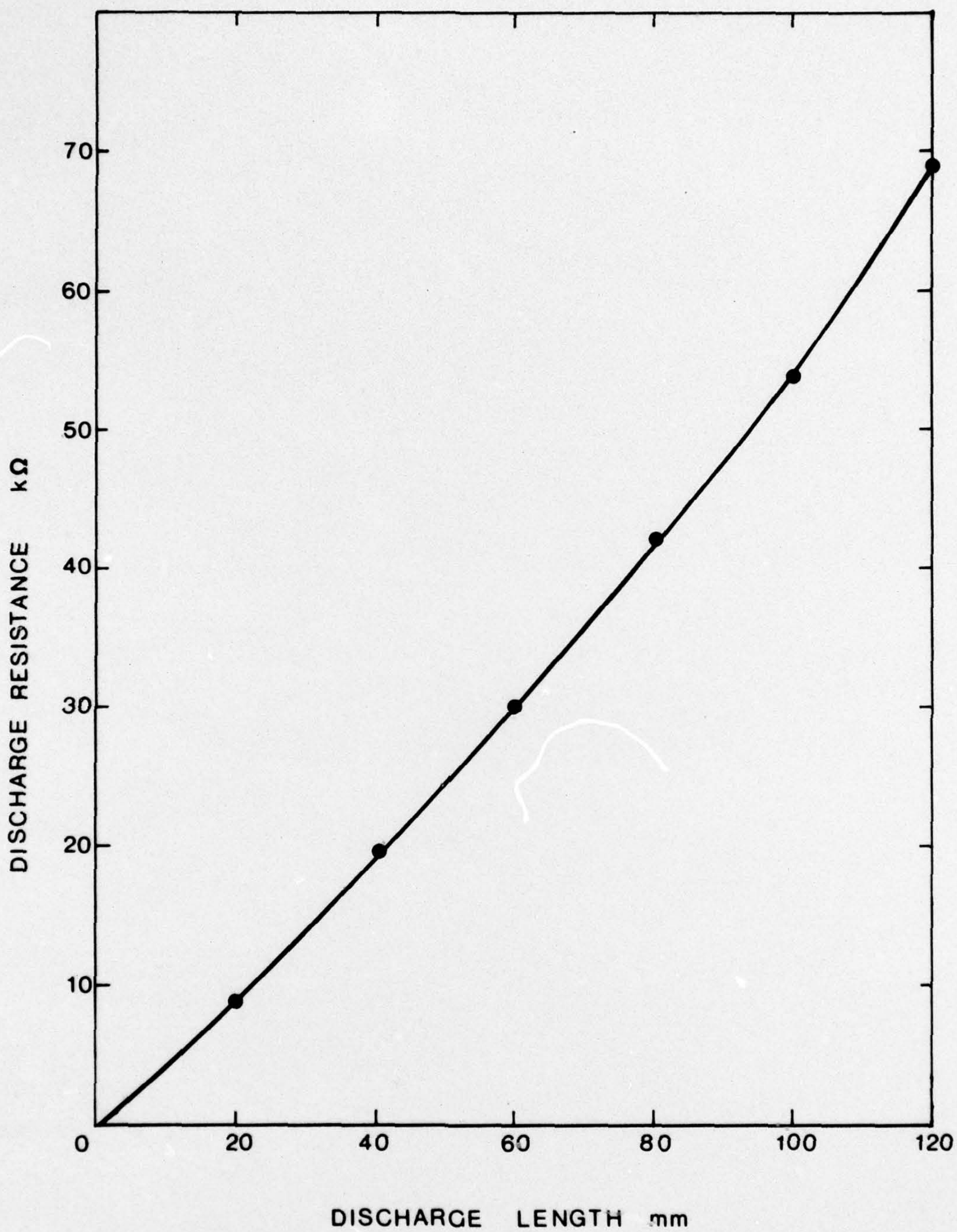

FIG. 5 - Discharge slope-resistance, in N_2, as a function of length, for I_p = 1.3 A, $\dot{m}$ = 34 gs^{-1} and P = 100 kPa.

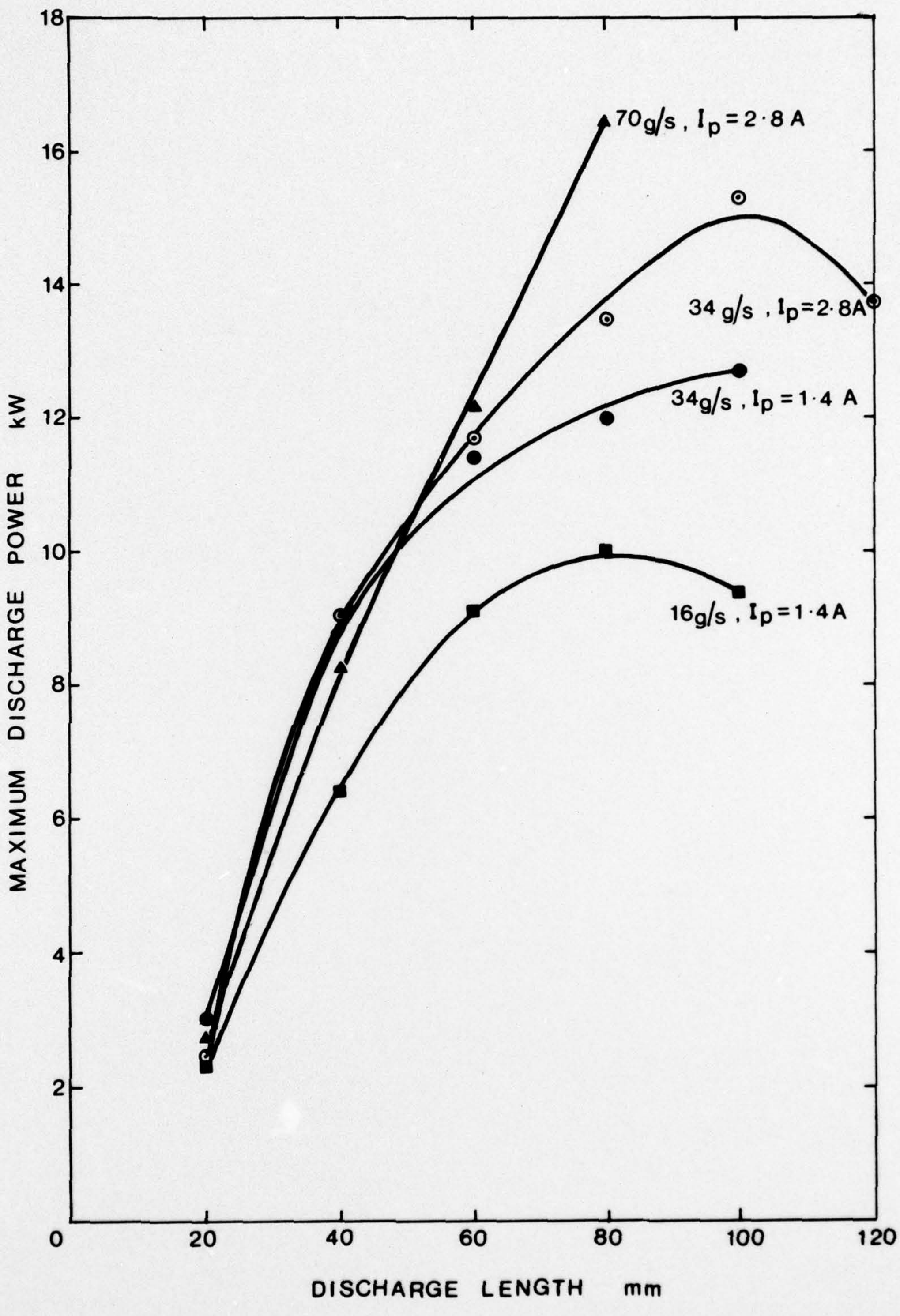

FIG. 6 - Maximum stable discharge power as a function of length, in N_2, at 100 kPa.

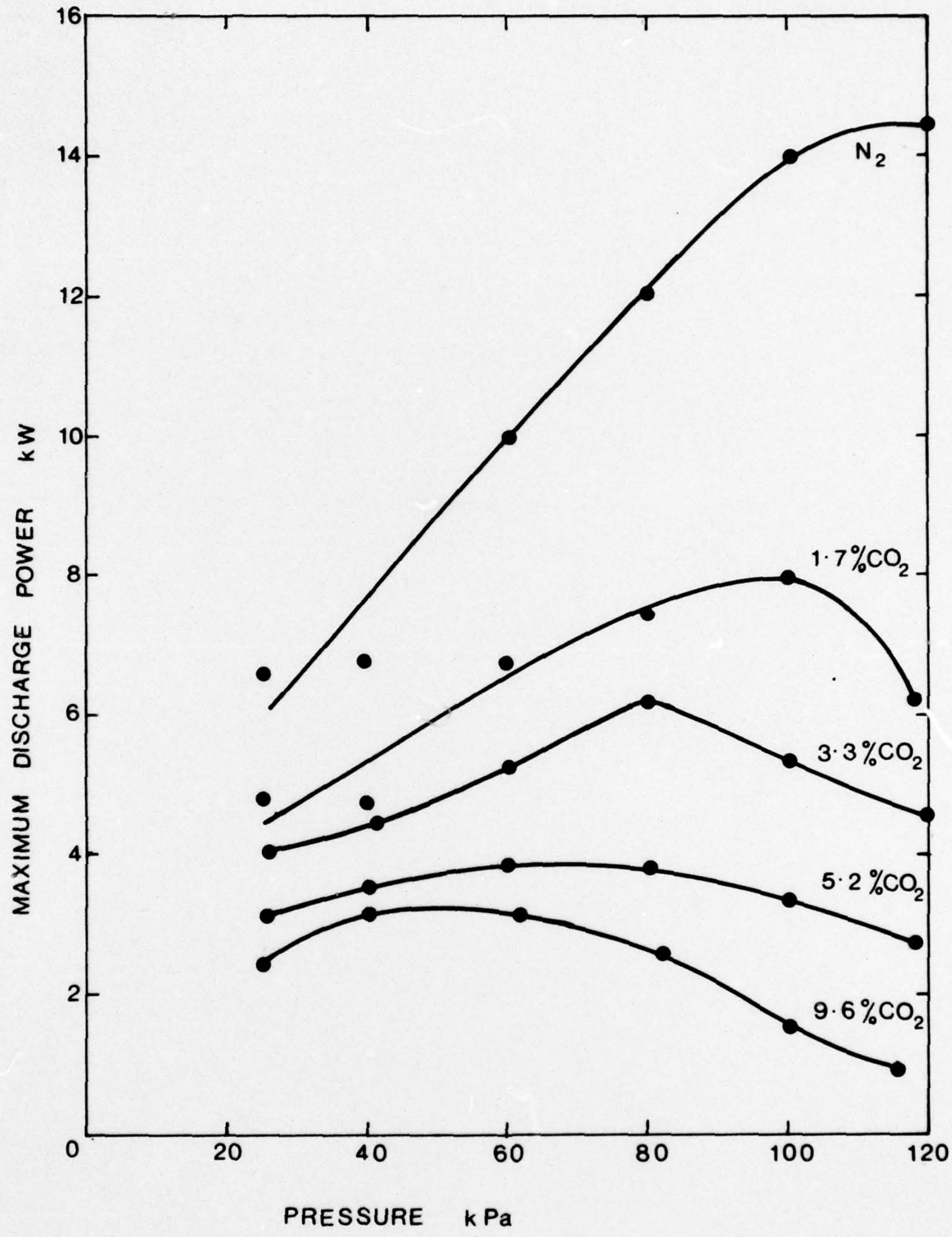

FIG. 7 - Maximum stable discharge power in different CO_2/N_2 gas mixtures as a function of pressure, for L = 60 mm, I_p = 1.3 A and $\dot{m}$ = 34 gs^{-1}.

DISTRIBUTION LIST

MATERIALS RESEARCH LABORATORIES

Chief Superintendent
Superintendent, Physics Division
Mr. L.E.S. Mathias
Dr. R. McLeary
Dr. P.J. Beckwith
Library
Branch Superintendent, S.A. Branch
Librarian, N.S.W. Branch (Through Officer-in-Charge)
Librarian, S.A. Branch
Officer-in-Charge, Joint Tropical Research Unit

DEPARTMENT OF DEFENCE

Chief Defence Scientist
Executive Controller, ADSS
Superintendent, Defence Science Administration, DSTO
Director, Joint Intelligence Organisation
Superintendent, Military Advisers Branch
Head, Laboratory Programs Branch
Army Scientific Adviser
Air Force Scientific Adviser
Naval Scientific Adviser
Mr. L.J. Dunne, Optics and Surveillance Division, Weapons Research Establishment
Wg Cdr. P. Grigg, SR (NAV) CAS Branch, RAAF
Chief Superintendent, Aeronautical Research Laboratories
Director, Weapons Research Establishment
Senior Librarian, Weapons Research Establishment
Librarian, R.A.N. Research Laboratory
Document Exchange Centre, DLIS (16 copies)
Principal Librarian, Campbell Park Library ADSATIS Annex
Directorate of Quality Assurance (Air Office)
Head, Engineering Development Establishment

DEPARTMENT OF INDUSTRY AND COMMERCE

NASA Canberra Office
Head, B.D.R.S.S. (Aust.)

OTHER FEDERAL AND STATE DEPARTMENTS AND INSTRUMENTALITIES

The Chief Librarian, Central Library, C.S.I.R.O.
Australian Atomic Energy Commission Research Establishment

DISTRIBUTION LIST

(Continued)

MISCELLANEOUS - AUSTRALIA

Dr. G.J.F. Troup, Department of Physics, Monash University
Dr. G.L. Brown, Department of Mechanical Engineering, University of Adelaide
Prof. S.C. Haydon, Department of Physics, University of New England

MISCELLANEOUS - OVERSEAS

Defence Scientific & Technical Representative, Department of Defence, England
Assistant Director/Armour and Materials, Military Vehicles and Engineering Establishment, England
Reports Centre, Directorate of Materials Aviation, England
Library - Exchange Desk, National Bureau of Standards, U.S.A.
U.S. Army Standardization Group, Office of the Scientific Standardization Representative, Canberra, A.C.T.
Senior Standardization Representative, U.S. Army Standardization Group, Canberra, A.C.T.
Chief, Research and Development, Defence Scientific Information Service, Canada (2 copies)
The Director, Defence Scientific Information and Documentation Centre, India
Colonel B.C. Joshi, Military, Naval and Air Adviser, High Commission of India, Red Hill, A.C.T.
Director, Defence Research Centre, Malaysia
Accessions Department, British Library, England
Official Publications Section, British Library, England
Librarian, Periodicals Recording Section, National Reference Library of Science and Invention, England
INSPEC: Acquisition Section, Institution of Electrical Engineers, England
Overseas Reports Section, Defence Research Information Centre, England
U.S. Army Electronics Command (Attn. DRSEL-CT-L/Dr. Hans Hieslmair),U.S.A.
Naval Surface Weapons Center (Attn. Mr. Walter Graham), U.S.A.
Defence Research and Development Staff, British Embassy, (Attn. Mr. Varnish, Washington Contact Officer), U.S.A.
Ministry of Defence, RSRE Baldock (Attn. Mr. Peter Lomer), England
Ministry of Defence, RSRE Malvern (Attn. Dr. K. Hulme), England
Ministry of Defence, RSRE Malvern (Attn. Dr. Peter Forrester), England
Canadian Defence Research Staff (Attn. Dr. Stindler), U.S.A.
Mr. William C. Schoonover, Air Force Avionics Laboratory, U.S.A.

DISTRIBUTION LIST

(Continued)

MISCELLANEOUS - OVERSEAS (Cont.)

Defence Research Establishment Valcartier (Attn. Dr. J.L. Lachambre), Canada
Counsellor Defence Science (Attn. Mr. M.K. Busch), U.S.A.
Dr. J.W. Rich, Calspan Corporation, U.S.A.
Dr. A.E. Hill, Air Force Weapons Laboratory, U.S.A.
Dr. A. De Maria, United Technologies Research Centre, U.S.A.
Dr. D.B. Cohn, Northrup Research and Technology Centre, U.S.A.